TO WHOM IT MAY CONCERN

I, Andreas Roth, of Saebener Str. 9, 81547 Muenchen, Germany, do hereby solemnly declare that I am conversant with both the English and German languages and that the enclosed English text is, to the best of my knowledge and belief, a true and accurate English translation of the German-language text of German patent application no. 102 44 586.9, filed by Carl Zeiss Jena GmbH on September 20, 2002.

Munich, this 4th day of September 2003.

A. Roth

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Öffentlich bestellter und beeidigter Übersetzer für die englische Sprache

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Certified Translation into English

Projection objective

The invention relates to a projection objective having a variable focal length, preferably serving to image tilting mirror matrices or reflecting and/or transmitting LCDs, said projection objective comprising three groups of lenses arranged on a common optical axis, wherein, starting from the side facing the projection screen, the first group of lenses, serving the purpose of focussing, and the second group of lenses, serving the purpose of varying the focal length, are arranged on the optical axis in a variably positioned manner, and the third group of lenses is stationary.

Generally known projection objectives having variable focal lengths and used especially for images of the aforementioned type, as described, for example, in EP 058 651 B1 and US 5,644,435, differ from each other essentially in the number of lenses, their arrangement and the technical construction data in connection with the conditions applicable to the optical system.

Since it is desirable for applications, in most cases, to vary the size and location of the image, thus adjusting the projection to the most diverse spatial dimensions, use is made mainly of zoom projection systems.

Therefore, projection objectives consist mainly of a zoom device, a compensating device and a focussing device of the type known from photographic lenses.

As a result thereof, in order to achieve a high image quality, such systems comprise many lens elements, are structurally very complex and, thus, very expensive.

Therefore, it is the object of the present invention, to provide a projection objective of the above-mentioned type, which reduces the technical complexity of its production due to a small number of optical elements having minimized dimensions, while simultaneously ensuring a good imaging performance.

According to the invention, this object is achieved in that the following conditions are met:

$$1.0\ h\ max < dG2\text{-}G3 < 1.5\ h\ max$$

and

$$s \leq 10\ mm,$$

wherein h max is the maximum object height, dG2-G3 is the distance between the group of lenses G2 and the group of lenses G3 in a first position, and s is the object-side intercept distance.

The projection objective according to the invention comprises relatively few optical elements and is, thus, very inexpensive to manufacture.

In order to improve its imaging performance, the projection objective is conveniently designed such that the following conditions are met:

$$1.2\ f1 < fG1 < 1.7\ f1,$$
$$0.7\ f1 < fG2 < 1.1\ f1,$$
$$1.5\ f1 < fG3 < 2.0\ f1,$$

wherein

f1 = the total focal length of the objective in a first position,
fG1 = the absolute value of the focal length of the first group of lenses G1,
fG2 = the absolute value of the focal length of the second group of lenses G2, and
fG3 = the absolute value of the focal length of the third group of lenses G3.

One embodiment according to the invention consists in that, starting from the side facing the projection screen,

- the first group of lenses consists of a
  negative meniscus,
  a positive meniscus and a negative lens,
- the second group of lenses consists of a
  negative meniscus or of a negative assembly which consists of a positive meniscus and of a negative meniscus,
  a positive lens and a positive assembly which consists of a positive lens and of a negative lens, and
- the third group of lenses consists of
  at least one positive lens.

Advantageous further embodiments of the projection objective according to the invention consist in that the following conditions are met:

$$2.0 < L / f1 < 30$$

$$1.68 < navg < 1.74$$

$$40.0 < vavg < 44.0,$$

wherein
L = the entire length of the objective,
navg = the average refractive index of the objective, and
vavg = the average value of the Abbe dispersion number of the objective.

The projection objective according to the invention will be explained in more detail with reference to embodiment examples. In doing so, identical reference numerals designate identical elements in the individual Figures, wherein:

- Fig.1 shows a schematic representation of the projection objective;
- Fig.2 shows a schematic representation of the projection objective with the assembly being arranged as the first element in the second group of lenses G2;
- Fig.3 shows a schematic representation of the radiuses Ri and of the air spaces or lens thicknesses di according to Fig. 2;
- Fig.4 shows a schematic representation of the projection objective with the meniscus lens being arranged as the first element in the second group of lenses G2;
- Fig. 5 shows a schematic representation of the radiuses Ri and of the air spaces or lens thicknesses di according to Fig. 4;
- Fig. 6 shows a graph of the imaging errors for the final positions of the focal length range (f = 19.2 and f = 22.5) of a first embodiment example according to Figures 2 and 3;
- Fig. 7 shows a graph of the imaging errors for the final positions of the focal length range (f = 25.8 and f = 30.0) of a second embodiment example according to Figures 2 and 3;
- Fig. 8 shows a graph of the imaging errors for the final positions of the focal length range (f = 19.2 and f = 22.5) of a first embodiment example according to Figures 4 and 5;
- Fig. 9 shows a graph of the imaging errors for the final positions of the focal length range (f = 25.8 and f = 30.0) of a second embodiment example according to Figures 4 and 5.

Fig. 1 shows the general structure of the projection objective comprising, starting from the projection screen 1 and arranged on the common optical axis 2, the first group of lenses G1, the second group of lenses G2 and the third group of lenses G3, wherein, as is evident from the second partial image, the second group of lenses G2, which is used for correction of the focal length (<-fok.->), occupies a changed (corrected) position on the optical axis 2. The third group of lenses G3 facing the object remains unchanged in its position on the optical axis 2, while the first group of lenses G1 is displaceably arranged for the purpose of focussing the objective.

Fig. 2 shows the schematic representation of the projection objective comprising a negative meniscus lens 3, a positive meniscus lens 4 as well as a negative lens 5, arranged in the group of lenses G1.
In this example, the group of lenses G2 consists of a positive meniscus lens 6 and a negative meniscus lens 7 (assembly), of a positive lens 8 and of a positive assembly consisting of a positive lens 9 and of a negative lens 10.
The group of lenses G3 is characterized by a positive lens 11.

Fig.3 shows the denoting of the radiuses Ri (i = 1 to 16) and the air spaces or lens thicknesses di (i = 1 to 16) of the variant of the projection objective shown in Fig.2. On this basis, said variant is represented by two embodiment examples differing in their constructional data. The constructional data of the embodiment examples thereof are shown in Tables 1 and 2 in conjunction with Table 5, which follow the embodiment examples.

In variation of the example according to Figs. 2 and 3, Fig. 4 shows the representation of the projection objective with a negative meniscus lens 12 being arranged as the first element in the second group of lenses G2, instead of the assembly consisting of the positive meniscus lens 6 and a negative meniscus lens 7. In addition, Fig. 5 shows the denoting of the radiuses Ri (i = 1 to 15) and the air spaces or lens thicknesses di (i = 1 to 14). Based thereon, this alternative embodiment is characterized by two embodiment examples differing in their constructional data, shown in Tables 3 and 4 in conjunction with Table 5.

Figures 6 and 7 are graphs showing the imaging errors for the end positions of the focal length range f = 19.2 or f = 22.5 (first embodiment example) and f = 25.8 and f = 30.0 (second embodiment example) according to the variant of the projection objective of Figures 2 and 3.

Analogous to this type of representation, Figures 8 and 9 show the imaging errors of both embodiment examples of the projection objective according to the arrangements of groups of lenses of Figures 4 and 5 for the same end positions of the focal length ranges.

Table 1

Radiuses	Thickness and air spaces	Refractive indices n_e	Abbe dispersion number v_e
R_1 = 40.10			
	d_1 = 1.50	n_1 = 1.70557	v_1 = 41.0
R_2 = 12.68			
	d_2 = 5.81		
R_3 = 17.70			
	d_3 = 2.76	n_2 = 1.79192	v_2 = 25.5
R_4 = 29.64			
	d_4 = 1.62		
R_5 = -114.59			
	d_5 = 2.02	n_3 = 1.59143	v_3 = 60.9
R_6 = 48.35			
	d_6 = 4.65		
R_7 = 13.63			
	d_7 = 2.80	n_4 = 1.80642	v_4 = 34.7
R_8 = 36.78			
	d_8 = 2.09	n_5 = 1.73429	v_5 = 28.2
R_9 = 9.86			
	d_9 = 1.08		
R_{10} = 21.13			
	d_{10} = 2.41	n_6 = 1.80811	v_6 = 46.3
R_{11} = -56.23			
	d_{11} = 0.11		
R_{12} = 11.55			
	d_{12} = 3.90	n_7 = 1.80811	v_7 = 46.3
R_{13} = -13.63			
	d_{13} = 1.18	n_8 = 1.67765	v_8 = 31.8
R_{14} = 8.29			
	d_{14} = 14.01		
R_{15} = 28.18			
	d_{15} = 7.17	n_9 = 1.67340	v_9 = 46.9
R_{16} = -113.02			

Variable lens position	air space	air space	focal length
1	d_6 = 4.65	d_{14} = 14.01	f'_1 = 19.2
2	d_6 = 2.12	d_{14} = 16.56	f'_2 = 22.3

Öffentlich bestellter und beeidigter Übersetzer für die englische Sprache
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Table 2

Radiuses	Thickness and air spaces	Refractive indices n_e	Abbe dispersion number v_e
R_1 = 60.43			
	d_1 = 1.80	n_1 = 1.67341	v_1 = 46.8
R_2 = 14.75			
	d_2 = 4.14		
R_3 = 18.97			
	d_3 = 2.94	n_2 = 1.69413	v_2 = 31.1
R_4 = 41.57			
	d_4 = 1.80		
R_5 = -76.63			
	d_5 = 1.60	n_3 = 1.52458	v_3 = 59.2
R_6 = 76.63			
	d_6 = 5.89		
R_7 = 17.15			
	d_7 = 3.41	n_4 = 1.83935	v_4 = 37.0
R_8 = 39.81			
	d_8 = 2.80	n_5 = 1.73430	v_5 = 28.2
R_9 = 11.97			
	d_9 = 1.17		
R_{10} = 24.76			
	d_{10} = 2.64	n_6 = 1.77621	v_6 = 49.4
R_{11} = -79.72			
	d_{11} = 0.20		
R_{12} = 14.23			
	d_{12} = 4.60	n_7 = 1.80832	v_7 = 46.3
R_{13} = -17.40			
	d_{13} = 1.20	n_8 = 1.65222	v_8 = 33.6
R_{14} = 10.37			
	d_{14} = 18.21		
R_{15} = 35.48			
	d_{15} = 8.10	n_9 = 1.67341	v_9 = 46.8
R_{16} = -347.16			

Variable lens position	air space	air space	focal length
1	d_6 = 5.89	d_{14} = 18.21	f'_1 = 25.8
2	d_6 = 2.55	d_{14} = 21.56	f'_2 = 30.0

Table 3

Radiuses	Thickness and air spaces	Refractive indices n_e	Abbe dispersion number v_e
R_1 = 43.80			
	d_1 = 3.00	n_1 = 1.67402	v_1 = 39.0
R_2 = 11.87			
	d_2 = 4.93		
R_3 = 16.30			
	d_3 = 2.50	n_2 = 1.72310	v_2 = 29.3
R_4 = 34.64			
	d_4 = 1.30		
R_5 = -112.67			
	d_5 = 2.60	n_3 = 1.61520	v_3 = 58.5
R_6 = 40.07			
	d_6 = 5.40		
R_7 = 12.65			
	d_7 = 3.74	n_4 = 1.81264	v_4 = 25.2
R_8 = 9.47			
	d_8 = 0.95		
R_9 = 19.32			
	d_9 = 2.43	n_5 = 1.75844	v_5 = 52.1
R_{10} = -40.60			
	d_{10} = 0.10		
R_{11} = 11.88			
	d_{11} = 4.23	n_6 = 1.79012	v_6 = 44.0
R_{12} = -9.94			
	d_{12} = 1.28	n_7 = 1.67765	v7 = 31.8
R_{13} = 8.28			
	d_{13} = 14.00		
R_{14} = 29.40			
	d_{14} = 6.30	n_8 = 1.67340	v_8 = 46.9
R_{15} = -108.14			

Variable lens position	air space	air space	focal length
1	d_6 = 5.40	d_{14} = 14.00	f'_1 = 19.2
2	d_6 = 2.96	d_{14} = 16.51	f'_2 = 22.3

Table 4

Radiuses		Thickness and air spaces		Refractive indices n_e		Abbe dispersion number v_e	
R_1 =	64.11						
		d_1 =	1.70	n_1 =	1.67402	v_1 =	39.0
R_2 =	15.05						
		d_2 =	4.59				
R_3 =	19.17						
		d_3 =	2.80	n_2 =	1.65222	v_2 =	33.6
R_4 =	56.56						
		d_4 =	1.75				
R_5 =	-89.83						
		d_5 =	1.54	n_3 =	1.48914	v_3 =	70.2
R_6 =	45.05						
		d_6 =	5.95				
R_7 =	16.13						
		d_7 =	6.46	n_4 =	1.70824	v_4 =	39.1
R_8 =	11.93						
		d_8 =	1.40				
R_9 =	21.84						
		d_9 =	2.60	n_5 =	1.80832	v_5 =	46.3
R_{10} =	-79.02						
		d_{10} =	0.10				
R_{11} =	13.81						
		d_{11} =	4.24	n_6 =	1.80832	v_6 =	46.3
R_{12} =	-17.01						
		d_{12} =	1.30	n_7 =	1.71142	v_7 =	30.0
R_{13} =	10.10						
		d_{13} =	18.19				
R_{14} =	35.42						
		d_{14} =	7.90	n_8 =	1.67341	v_8 =	46.8
R_{15} =	-348.47						

Variable lens position	air space		air space		focal length	
1	d_6 =	5.95	d_{14} =	18.19	f'_1 =	25.8
2	d_6 =	2.57	d_{14} =	21.55	f'_2 =	30.0

Table 5

Embodiment example	Table 1	Table 2	Table 3	Table 4
max. angle of aperture [°]	11.1	10.3	10.9	10.3
max. aperture ratio	1 : 2.6	1 : 2.8	1 : 2.6	1 : 2.8
zoom factor f'_2 / f'_1	1.2	1.2	1.2	1.2
focal length, first group	-27.7	-37.0	-27.2	-37.2
focal length, second group	17.3	21.8	16.9	22.0
focal length, third group	34.2	48.2	35.0	48.1
Total focal length f'1 of the system	19.25	25.8	19.26	25.8
focal length, first group / f'1	-1.44	-1.44	-1.41	-1.44
focal length, second group / f'1	0.90	0.85	0.88	0.85
focal length, third group / f'1	1.78	1.87	1.82	1.87
object-side intercept distance	4.3	6.0	4.7	6.1
object-side intercept distance / f'1	0.22	0.23	0.24	0.24
objective length	53.1	60.5	52.8	60.5
objective length / f'1	2.76	2.34	2.74	2.34
maximum object height	10.9	13.8	10.9	13.8
distance (2nd group - 3rd group in position 1)	14.0	18.2	14.0	18.2
distance / max. object height	1.29	1.33	1.28	1.33
average refractory index	1.73299	1.70844	1.71557	1.69064
average Abbe dispersion number	40.2	42.0	40.8	43.9

List of reference numerals

1	Projection screen
2	Optical axis
3 to 12	Lens
R	Radius
G1,G2,G3	Group of lenses
d	air space, lens thickness
f	Focal length

Claims

1. A projection objective having a variable focal length, preferably serving to image tilting mirror matrices or reflecting and/or transmitting LCDs, said projection objective comprising three groups of lenses (G1, G1, G3) arranged on a common optical axis (2), wherein, starting from the side facing the projection screen (1), the first group of lenses (G1), serving the purpose of focussing, and the second group of lenses (G2), serving the purpose of varying the focal length, are arranged on the optical axis (2) in a variably positioned manner, and the third group of lenses (G3) is stationary, characterized in that the following conditions are met:

$$1.0\ h\ max < dG2\text{-}G3 < 1.5\ h\ max$$

and

$$s \leq 10\ mm,$$

wherein h max is the maximum object height, dG2-G3 is the distance between the group of lenses G2 and the group of lenses G3 in a first position, and s is the object-side intercept distance.

2. The projection objective as claimed in Claim 1, characterized in that the following condition is met:

$$1.2\ f1 < fG1 < 1.7\ f1,$$

wherein f1 is the total focal length of the objective in a first position and fG1 is the absolute value of the focal length of the first group of lenses G1.

3. The projection objective as claimed in Claim 1, characterized in that the following condition is met:

$$0.7\ f1 < fG2 < 1.1\ f1,$$

wherein fG2 is the absolute value of the focal length of the second group of lenses G2.

4. The projection objective as claimed in Claim 1, characterized in that the following condition is met:

$$1.5\ f1 < fG3 < 2.0\ f1,$$

wherein fG3 is the absolute value of the focal length of the third group of lenses G3.

5. The projection objective as claimed in Claims 1 to 4, characterized in that, starting from the side facing the projection screen (1):

- the first group of lenses (G1) consists of a negative meniscus (3), a positive meniscus (4) and a negative lens (5),
- the second group of lenses (G2) consists

of a negative meniscus (12) or of a negative assembly consisting of a positive meniscus (6) and a negative meniscus (7),

of a positive lens (8) and of a positive assembly consisting of a positive lens (9) and a negative lens (10), and

- the third group of lenses (G3) consists of
  at least one positive lens (11).

6. The projection objective as claimed in any one of the preceding Claims, characterized in that the following condition is met:

$$2.0 < L / f1 < 3.0,$$

wherein L is the entire length of the objective.

7. The projection objective as claimed in any one of the preceding Claims, characterized in that the following condition is met:

$$1.68 < navg < 1.74,$$

wherein navg is the average refractive index of the objective.

8. The projection objective as claimed in any one of the preceding Claims, characterized in that the following condition is met:

$$40.0 < vavg < 44.0,$$

wherein vavg is the average value of the Abbe dispersion number of the objective.

Abstract

A projection objective having a variable focal length, preferably serving to image tilting mirror matrices or reflecting and/or transmitting LCDs, said projection objective comprising three groups of lenses (G1, G1, G3) arranged on a common optical axis (2), wherein, starting from the side facing the projection screen (1), the first group of lenses (G1), serving the purpose of focussing, and the second group of lenses (G2), serving the purpose of varying the focal length, are arranged on the optical axis (2) in a variably positioned manner, and the third group of lenses (G3) is stationary.

According to the invention, the following condition is met:

$$1.0 \text{ h max} < \text{dG2-G3} < 1.5 \text{ h max}$$

and

$$s \leq 10 \text{ mm},$$

wherein h max is the maximum object height, dG2-G3 is the distance between the group of lenses G2 and the group of lenses G3 in a first position, and s is the object-side intercept distance.

Fig.1

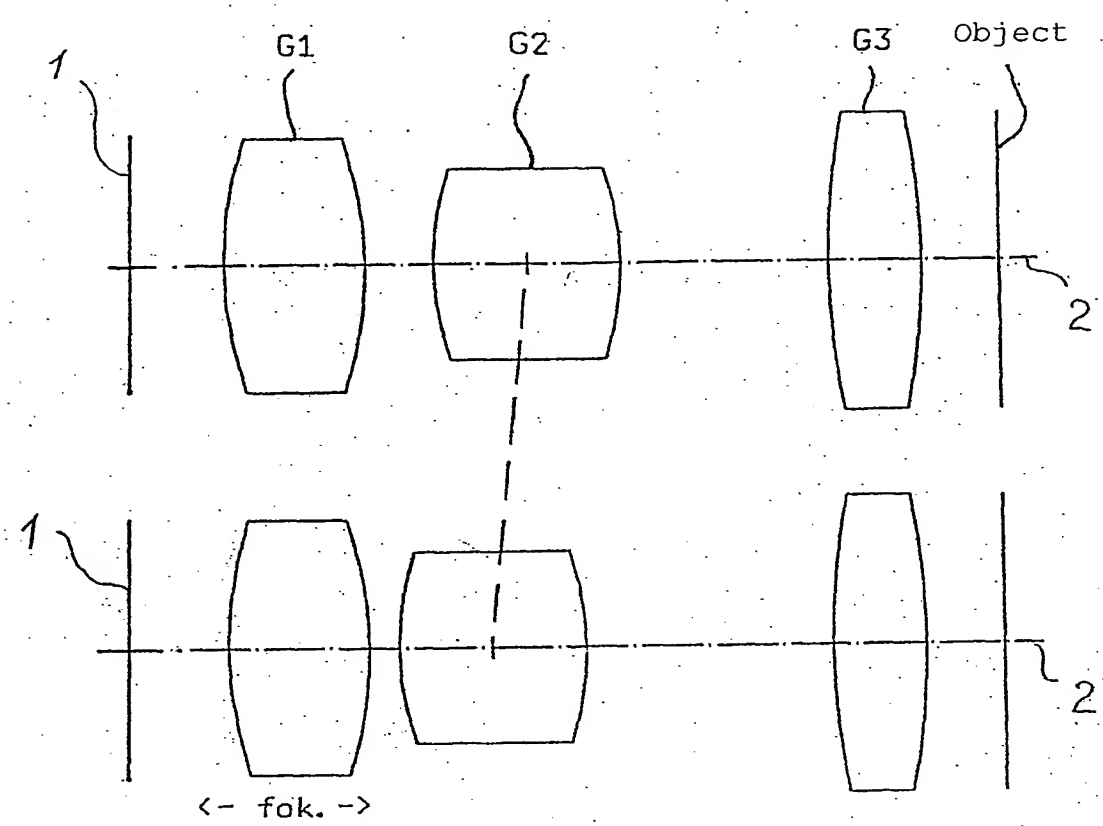


Fig. 1

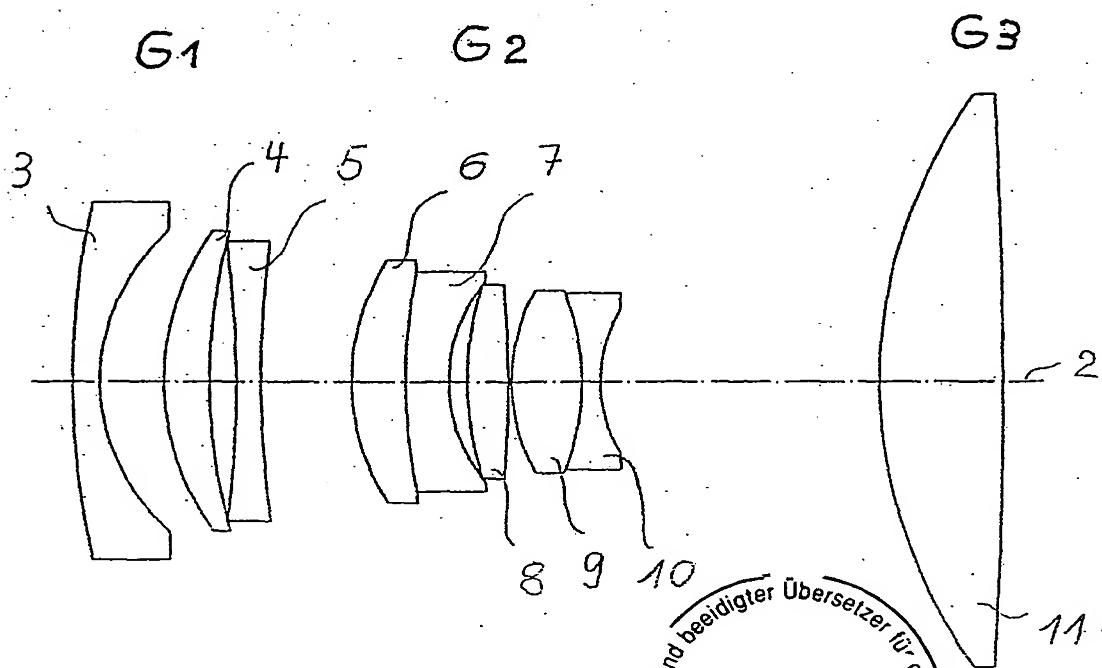


Fig. 2

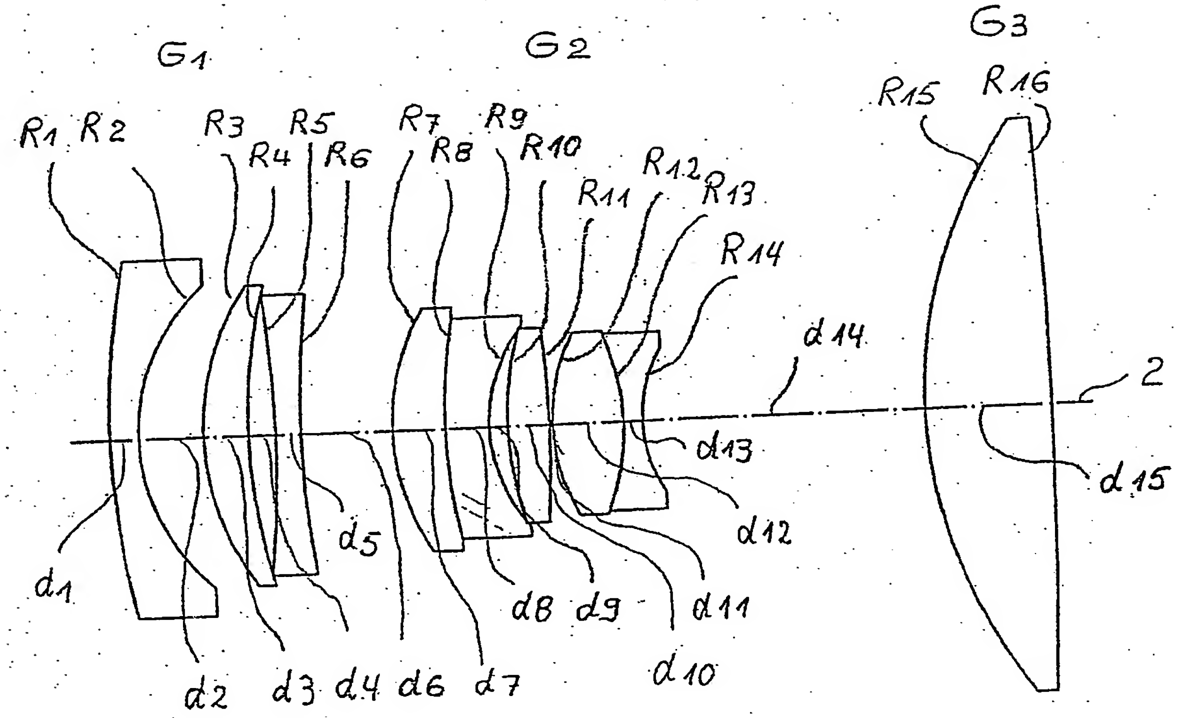

G1
G2
G3
R1 R2
R3
R4
R5
R6
R7
R8
R9
R10
R11
R12
R13
R14
R15
R16
d14
2
d13
d15
d12
d5
d1
d8 d9
d11
d10
d2 d3 d4 d6 d7

Fig. 3

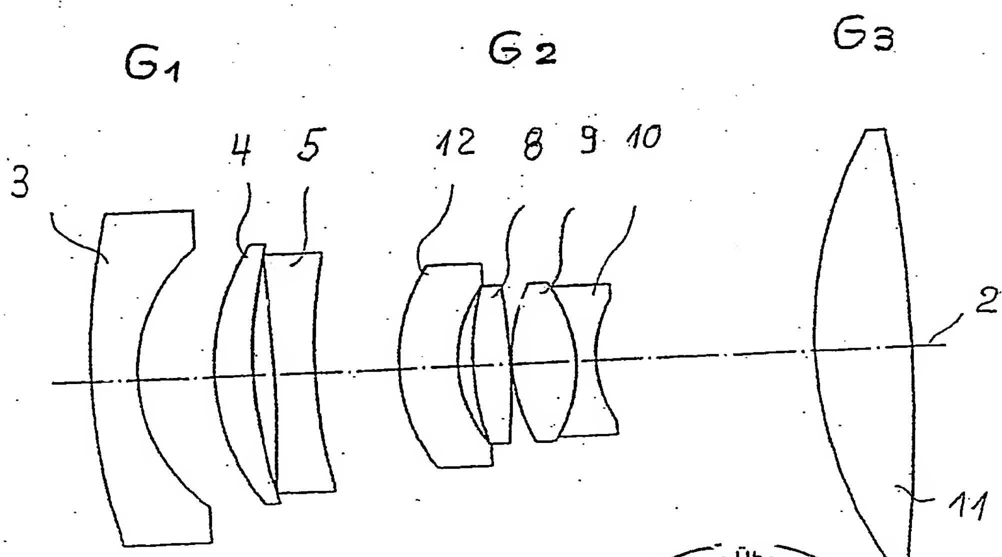

G1
G2
G3
3
4 5
12 8 9 10
2
11

Fig. 4

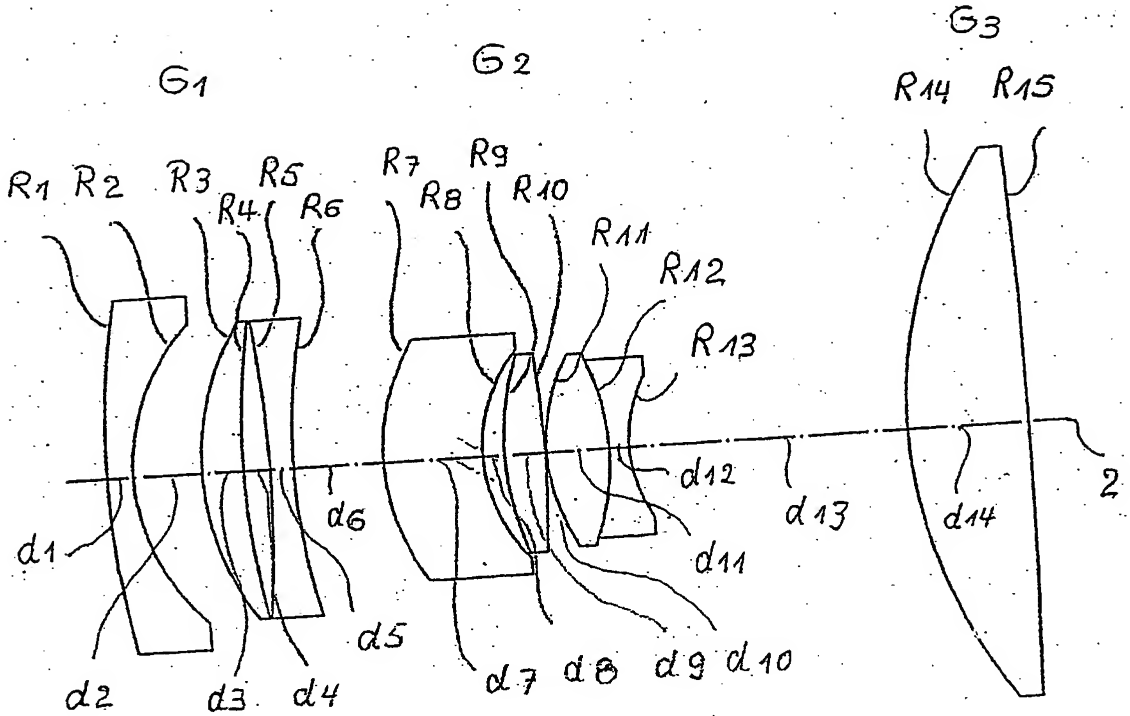

G1
G2
G3
R1 R2 R3 R4 R5 R6
R7 R8 R9 R10 R11 R12 R13
R14 R15
d1 d2 d3 d4 d5 d6
d7 d8 d9 d10 d11 d12 d13 d14
2

Fig. 5

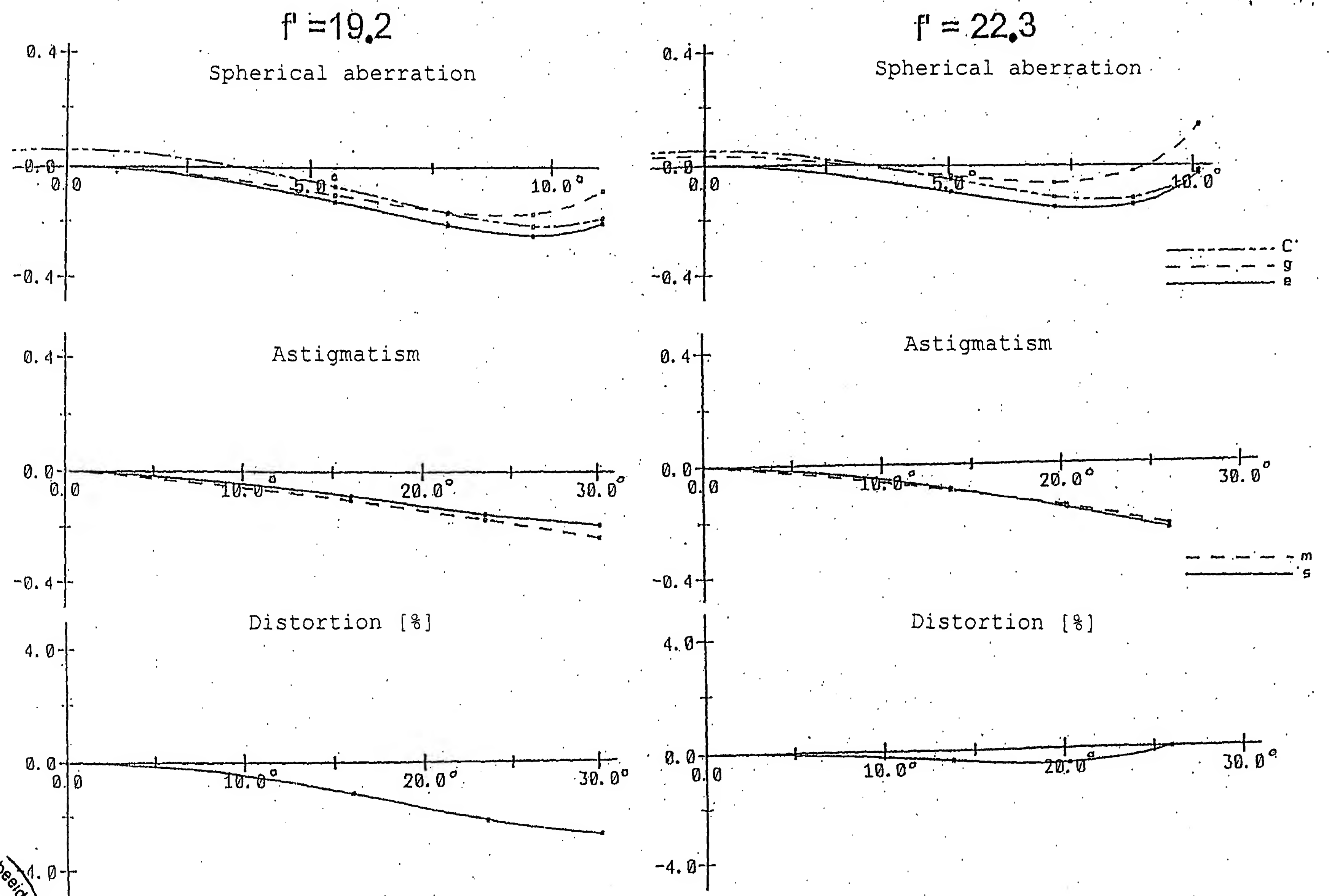
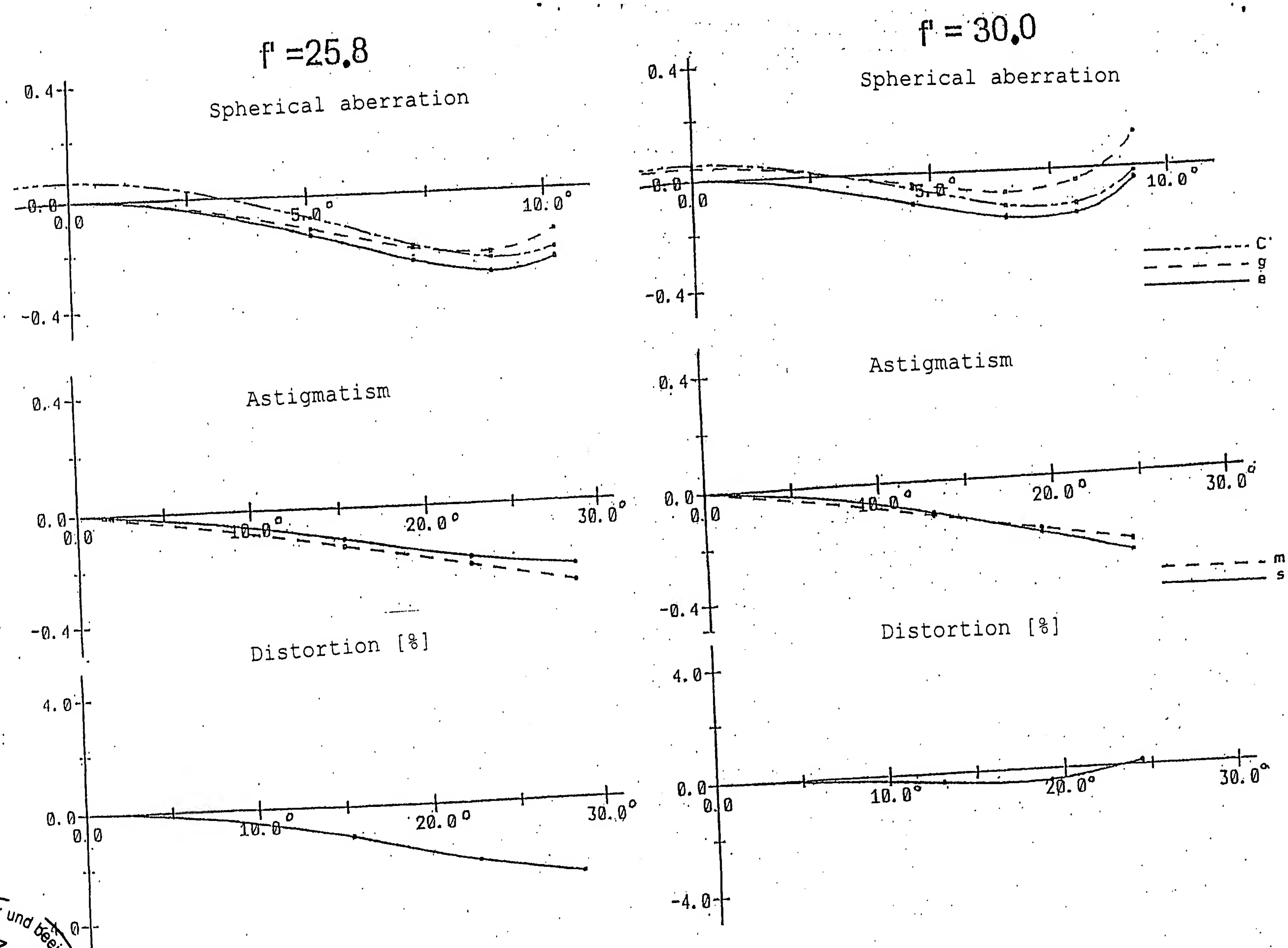
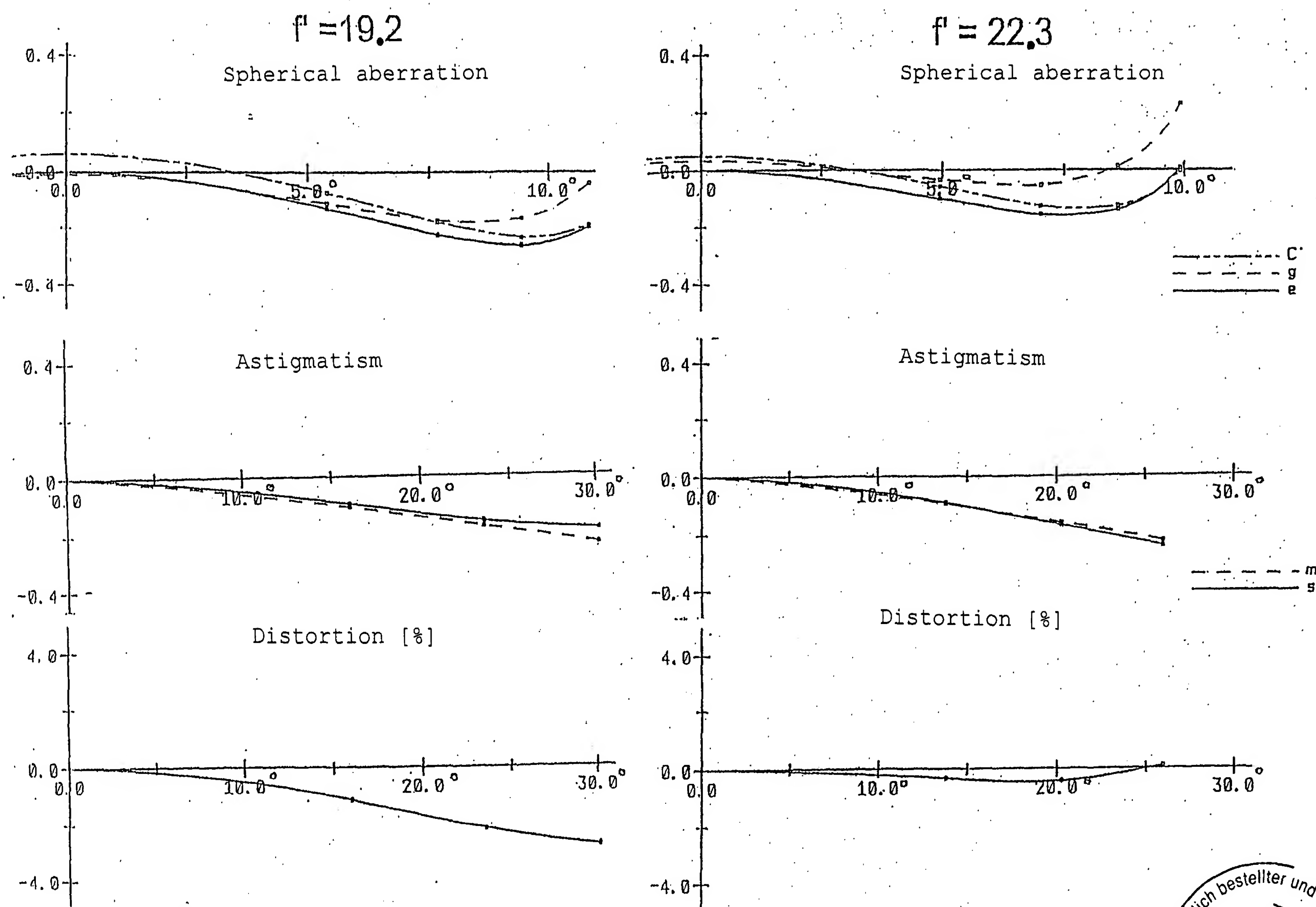

f' =19.2
f' = 22.3
Spherical aberration
Astigmatism
Distortion [%]
0.4
0.0
-0.4
4.0
-4.0
5.0°
10.0°
20.0°
30.0°
C'
g
e
m
s

FIG.6



f' =25.8
Spherical aberration
0.4
0.0
-0.4
0.0
5.0°
10.0°
Astigmatism
0.4
0.0
-0.4
0.0
10.0°
20.0°
30.0°
Distortion [%]
4.0
0.0
0
0.0
10.0°
20.0°
30.0°
f' = 30.0
Spherical aberration
0.4
0.0
-0.4
0.0
5.0°
10.0°
C'
g
e
Astigmatism
0.4
0.0
-0.4
0.0
10.0°
20.0°
30.0°
m
s
Distortion [%]
4.0
0.0
-4.0
0.0
10.0°
20.0°
30.0°

FIG.7



f' =19.2
Spherical aberration
Astigmatism
Distortion [%]
f' = 22.3
Spherical aberration
Astigmatism
Distortion [%]
C'
g
e
m
s
0.4
0.0
-0.4
4.0
-4.0
5.0°
10.0°
20.0°
30.0°

FIG.8

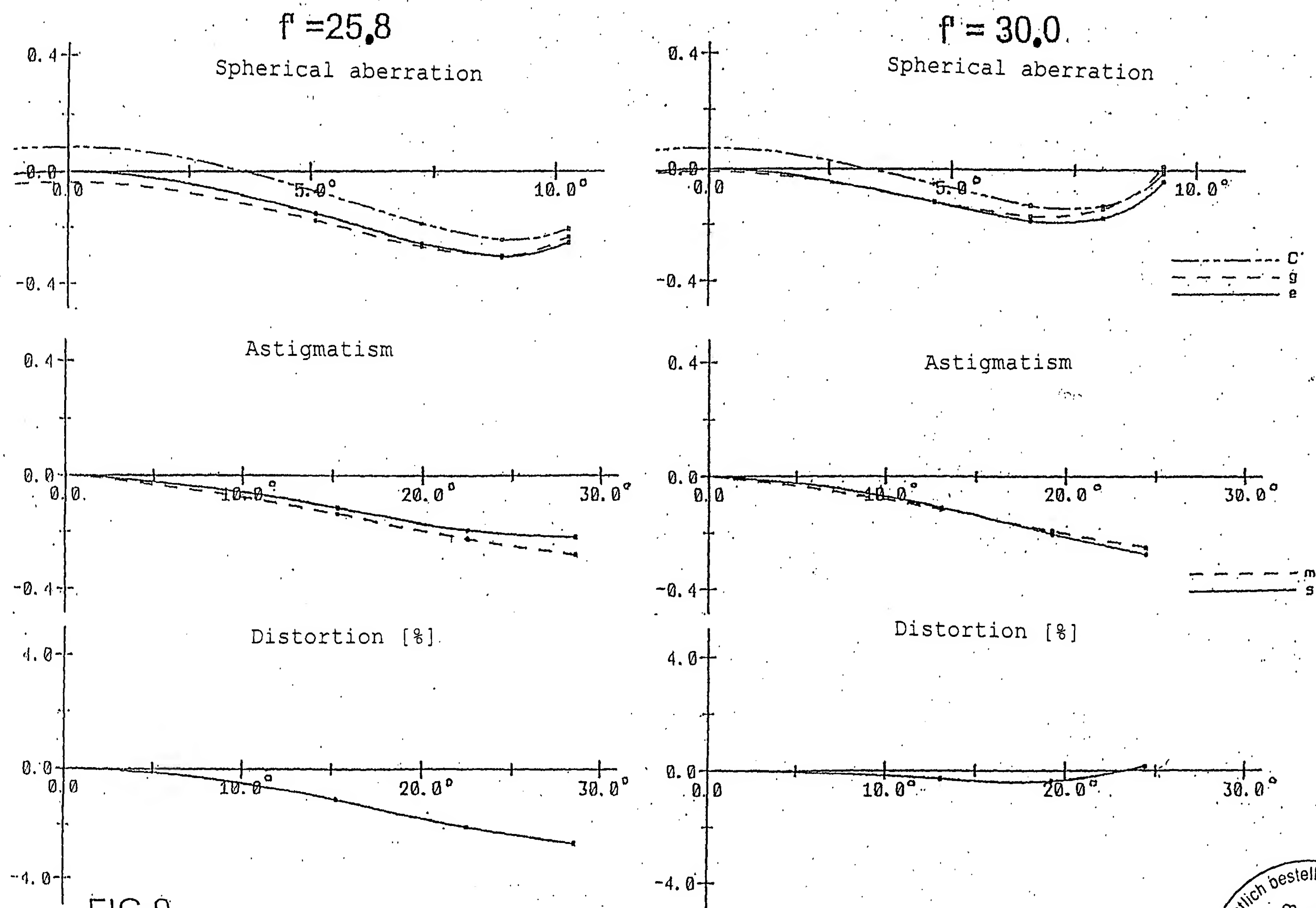

f' =25.8
f' = 30.0
Spherical aberration
Astigmatism
Distortion [%]
0.4
0.0
-0.4
4.0
-4.0
0.0
5.0°
10.0°
20.0°
30.0°
C'
g
e
m
s

FIG.9